UNCLASSIFIED

63-2-3

BRL

TECHNICAL NOTE NO. 1473
SEPTEMBER 1962

SOME EXPERIMENTS WITH THE LIQUID-FILLED, IMPULSIVELY STARTED, SPINNING CYLINDER

Gene Sokol

Department of the Army Project No. 503-03-001
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

ASTIA AVAILABILITY NOTICE

Qualified requestors may obtain copies of this report from ASTIA.

The findings in this report are not to be construed as an official Department of the Army position.

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

TECHNICAL NOTE NO. 1473

SEPTEMBER 1962

SOME EXPERIMENTS WITH THE LIQUID-FILLED, IMPULSIVELY STARTED, SPINNING CYLINDER

Gene Sokol

Exterior Ballistics Laboratory

Department of the Army Project No. 503-03-001

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

TABLE OF CONTENTS

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

TECHNICAL NOTE NO. 1473

GSokol/ic
Aberdeen Proving Ground, Md.
September 1962

SOME EXPERIMENTS WITH THE LIQUID-FILLED, IMPULSIVELY STARTED, SPINNING CYLINDER

ABSTRACT

This note is a description of some experiments with the liquid filled, impulsively started spinning cylinder. The main emphasis in these experiments was directed toward studies of secondary motions within the fluid. The variables of these experiments were the geometry of cylindrical cavity and fluid viscosity.

1. INTRODUCTION

It has been observed (1) that the liquid filled spinning projectiles are dynamically unstable during the unsteady phase of liquid motion while the liquid is acquiring a rigid body rotation. Also it has been shown that the duration of this unsteady phase is considerably shortened by presence of secondary flows within the liquid. These secondary flows serve as an effective mechanism for diffusion of vorticity throughout the liquid thereby expediting the attainment of a steady state or rigid body rotation. Hence, secondary flows are important in the liquid filled shell dynamics.

Present experiments, to be described in this report, are essentially a continuation of investigations briefly outlined in reference 2. The principal emphasis was placed on recording the development of secondary flows as these are affected by the different geometries of the cylindrical cavity and by the liquid viscosity.

The development of secondary flow can be schematically outlined as follows. Referring to Figure 1, the fluid particles which lie against the cylinder (in regions A, B, A', and B') are assumed to have an angular velocity equal to that of the cylinder at all times. Therefore the fluid particles in these regions have a higher angular velocity during an acceleration of the fluid than the angular velocity of fluid particles located elsewhere in the cylinder. Thus a particle of liquid (at a given radius) touching the end of the cylinder (in region A) has a greater angular velocity than the angular velocity of a particle of liquid of the same radius but located in region D. This difference in angular velocity causes a corresponding difference of centrifugal forces on particles of fluid located in different regions of the cylinder. Therefore liquid particles in region A are forced radially outward. Liquid in region D must move to replace the liquid that was in region A since the cylinder is completely filled with liquid. Liquid in region C must move inward (radially) and then upward to replace the liquid that was in region D. Liquid in region B must move downward to replace the liquid that was in region C. In the bottom-half of the cylinder, a flow pattern exists which is symmetrical (with respect to the horizontal mid-plane of the cylinder, $z = 0$) to the flow in the upper half.

2. EXPERIMENTAL APPARATUS

The equipment that is used to obtain the films from which the secondary flow pattern is studied is shown in the experimental apparatus photograph, Figure 2. This equipment is described in detail in reference 2. The apparatus has a flywheel and clutch assembly which allows the flywheel to be rotated at some constant speed (by an air turbine) while the cylinder remains at rest. Once the flywheel has achieved a desired angular velocity, a spring is released which forces the clutch plates together. The cylinder is then accelerated to a predetermined angular velocity (slightly less than that of the flywheel before the clutch was released). Once the cylinder and flywheel reach the same angular velocity, then they continue to rotate at that angular velocity. The "impulsive" spin-generator accelerates the cylinder from rest to 3000 revolutions per minute in approximately 1/10 second. Either solid particles or clouds of dye are suspended in the liquid in the cylinder and high speed motion pictures are taken of the motion of the particles or dye. Care is taken to get the densities of the particles or dyes to be as close as possible to the density of the liquid. This justifies the basic assumption that the solid particles or clouds of dye move as though they were particles of the primary liquid in the cylinder.

If solid particles are to be used, in order to photograph the secondary fluid motion in the cylinder, then the properties of the solid particles such as density, shape, size, and solubility, become important.

It is evident that if a sufficient difference in density exists between the liquid that fills the cylinder and the solid particles suspended in that liquid, then the solid particles will not have the same motion as the particles of liquid near them. Not only will the solid particles have a tendency to sink or float but also they will be forced to move radially inward or outward due to the centrifugal force of rotation. At high angular velocities, the cylinder acts like a centrifugal separator (like the ones found in chemical laboratories). This similarity suggested the use of the cylinder to separate the particles of acceptable density from those having unacceptable densities. Even among particles of the same compound from the same container there exist differences in density which are large enough to render over half of the particles unacceptable.

The ideal size and shape of a solid particle for use in the spinning cylinder experiments would be a small sphere. Large, solid particles would have a lesser likelihood to move like a particle of the liquid in the cylinder than would small, solid particles. Also large particles have more of a tendency to tumble than do small particles. If a particle tumbles, then this implies that some portion of the energy given to the solid particle (by the liquid particles near it) was used to rotate the solid particle about its own axis. However the solid particles must be large enough to be photographed at high film speeds.

For the experiments to be described in this report, the solid particles were first screened for size and shape and then rotated in the cylinder to obtain the ones of acceptable density. See the photograph of the actual particles used in the experiments, Figure 3. The liquid in the cylinder magnifies the particles about two or three times and makes them appear larger than their actual size.

3. EXPERIMENTS WITH SOLID PARTICLES SUSPENDED IN A LIQUID

The experiments involving the spinning cylinder (in which there are solid particles suspended in a liquid) have been carried on for the past three summers. The purpose of the first experiments was to determine the effects of the final angular velocity of the cylinder upon the secondary fluid motion. Experiments were made at 500, 1500, 3000, and 7000 revolutions per minute. In each of these experiments the same cylinder, the same liquid, and the same particles were used. Thus the fineness ratio of the cylinder (the height of the cylindrical cavity divided by its diameter) and the viscosity of the liquid were held constant and only the final angular velocity of the cylinder was varied. For these experiments the finess ratio was 2.88 and the liquid was a glycerin-water solution having a viscosity of 7.1 centipoises and a density of 1.15 grams/cc. Some of the results of these experiments are summarized in figures 4 and 5. Figure 4 shows measured particle trajectories at a specified experimental conditions. The principal motion of the fluid is rotation about the spin axis. Superimposed upon this motion are illustrated secondary flows which form a two cell structure within the rotating cylinder. Figure 5 shows the consequence of secondary motions as they affect the main flow. It is seen that, at a given

time, the distribution of vorticity in the main flow is different from what would be the case in the absence of secondary flows. The fluid, in effect, appears to be of higher viscosity than its real viscosity[3]. The subsequent experiments have not, as yet, been analyzed, so only the experimental conditions will be briefly described with some pictorial illustrations.

Two experiments were performed to compare the fluid motion in a partially filled cylinder with that in the completely filled cylinder. One film was taken of a 3/4 filled cylinder and one film of a completely filled cylinder. A cylinder with a fineness ratio of 2.88 and a liquid with a viscosity of 270 centipoises and density of 1.243 grams/cc were used in both experiments. Both experiments were made at 3000 rpm. Thus the viscosity, the fineness ratio, and the final angular velocity of the cylinder were the same in both experiments and only the amount of liquid in the cylinder was different.

The main purpose of the next six experiments was to provide information concerning the effect of the fineness ratio of the cylinder upon the secondary flow. All six experiments were run at 3000 rpm. Three cylinders were used. They had fineness ratios of 2.88, 5.78, and 1.44 (see Figure 6). Two viscosities were achieved (using the same liquid) by running the experiments at 78 degrees Fahrenheit and 88 degrees Fahrenheit. The viscosity of a 98 percent glycerin-water solution (the one which was used) is very dependent upon temperature. At 78 degrees Fahrenheit, the viscosity was 600 centipoises, and at 88 degrees Fahrenheit, the viscosity was 375 centipoises. The density of a glycerin-water solution does not vary enough with a change in temperature of 10 degrees Fahrenheit to cause an unacceptable density difference between the particles and the liquid.

Some experiments were run using the cylinder with hemispherical ends, Figure 7. The hemispherically ended cylinder will provide the means to investigate the relative importance of the corners in controlling the secondary flow.

4. EXPERIMENTS WITH DYES

In order to better visualize the secondary fluid motion and also to study some specialized problems, experiments have been made with clouds of dyes suspended in the liquid in the cylinder. One of the first experiments was

to show vividly that the secondary fluid motion divided the liquid in the cylinder into two distinct cells as was shown by particle motions. The dye was deposited on the axis, at the bottom and at the top of the cylinder prior to spinning and the cylinder was then spun. The dye spread throughout each half of the cylinder leaving a distinct uncolored boundary across the horizontal mid-plane of the cylinder. This is illustrated by Figure 8. The boundary remained distinct long after the liquid reached a rigid body rotation.

To study the development of secondary flows, blobs of dye were deposited at various positions within the cylinder and photographs were made of the history of dye's motion. One of the sequences is shown on Figure 9. In this case a phenolphthalein indicator was used in a 55 percent glycerin - sodium hydroxide solution. The viscosity of the resulting solution was about 7.1 centipoises. It is seen that two blobs of dye, located in the lower half of the cylinder, are first drawn toward the base, then spread along the base and up along the walls of the cylinder. Discolored fluid remains in the lower half of the cylinder for a long time. High speed camera photographs with timing pips of this process permits measurement of velocities for rather detailed examination of the development of secondary flows. The particles of dissolved dye in the injected clouds of dye are very small (probably of molecular size) and their motion should very nearly duplicate the motion of liquid particles in similar locations in the cylinder. One disadvantage is that the presence of dye on the periphery of the cylinder hides from view any motion within. In this respect, visual observations sometimes are more informative than the photographic ones for seeing gross development of the flow.

5. SUMMARY

The purpose of these experiments with the spinning cylinder was to elucidate further the development of secondary motions as these are influenced by the geometry of the cylinder and by the liquid viscosity. Again, suspended solid particles were used to trace the paths of fluid particles, a technique which proved fruitful in previous experiments. In addition, dyes were used in tracing the development of secondary flows. Some of the results are illustrated by photographs. The films are being measured to extract quantitative data.

ACKNOWLEDGEMENT

I would like to thank Dr. Boris Karpov for his many helpful suggestions concerning the experiments discussed in this report.

GENE SOKOL

REFERENCES

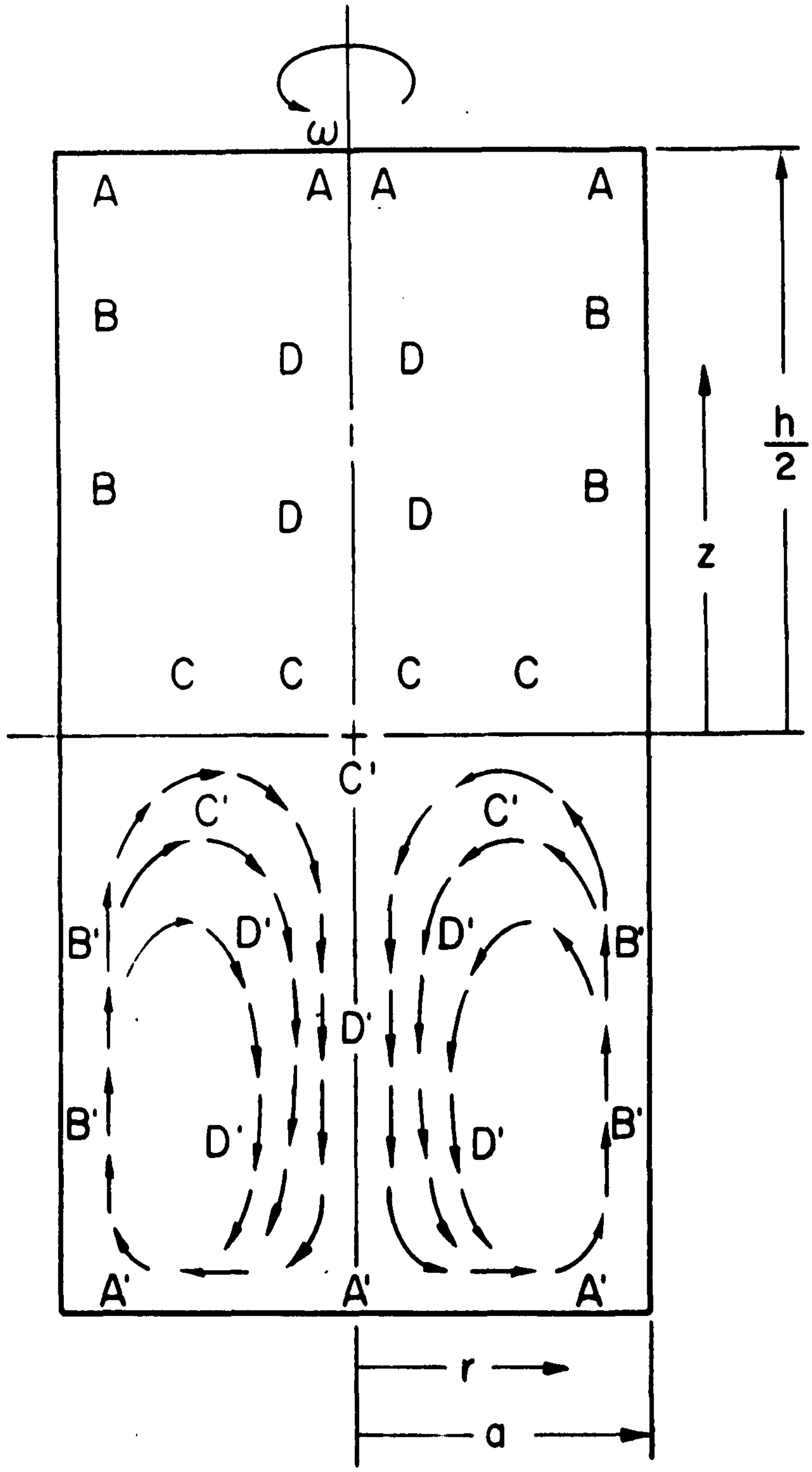
1. Karpov, B. G., Experimental Study of the Dynamics of Liquid Filled Shell, BRL Report No. 1171, September 1962.

2. Stoller, Harold M., Apparatus for Study of Fluid Motion in A Spinning Cylinder, BRL Technical Note No. 1355, October 1960.

3. Scott, W. E. A Theoretical Analysis of The Axial Spin Decay of a Spin Stabilized Liquid Filled Shell, BRL Report 1170, August 1962.

FIGURE 1 SECONDARY FLOW PATTERN

(For a cylinder accelerated from rest and completely filled with liquid)



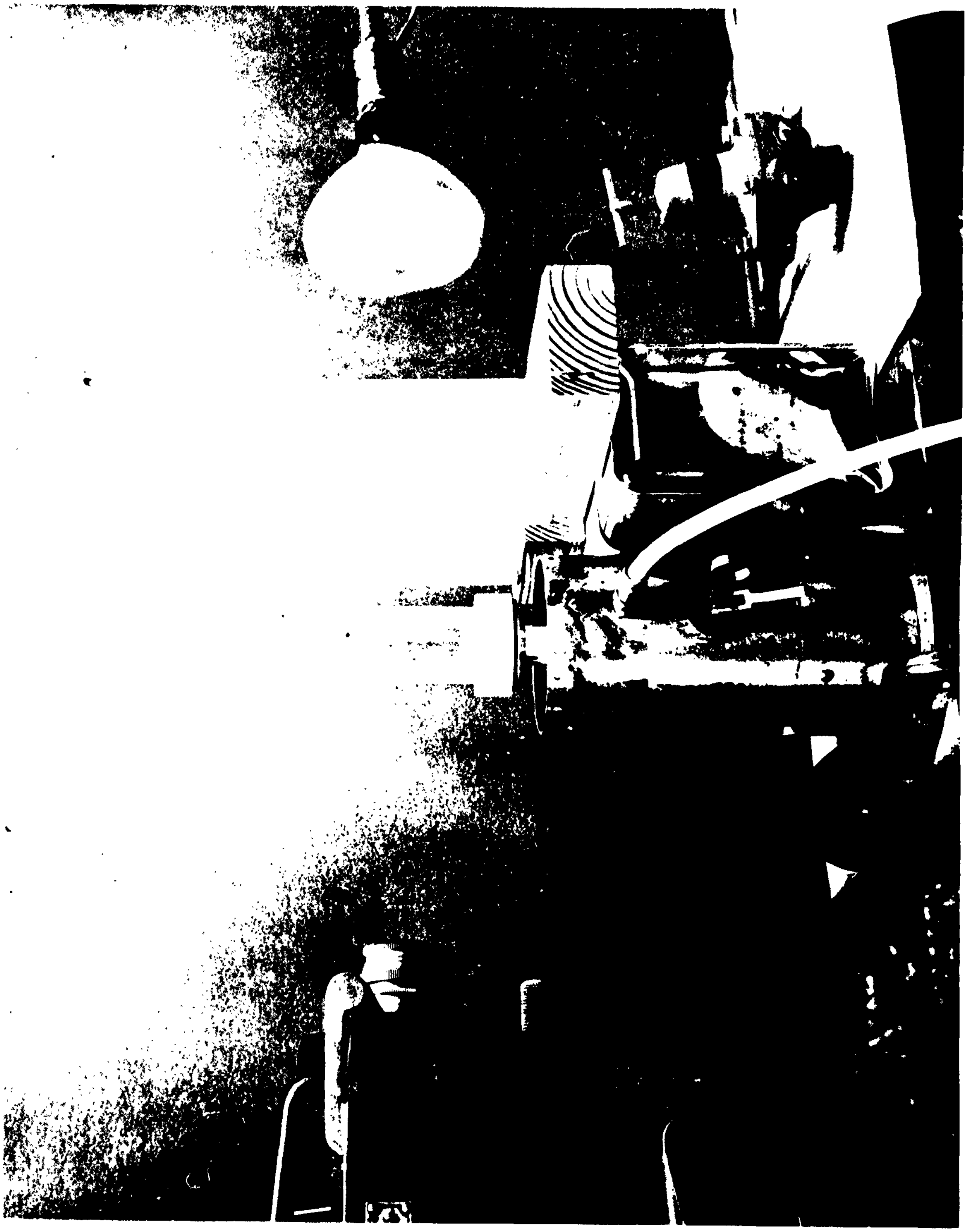
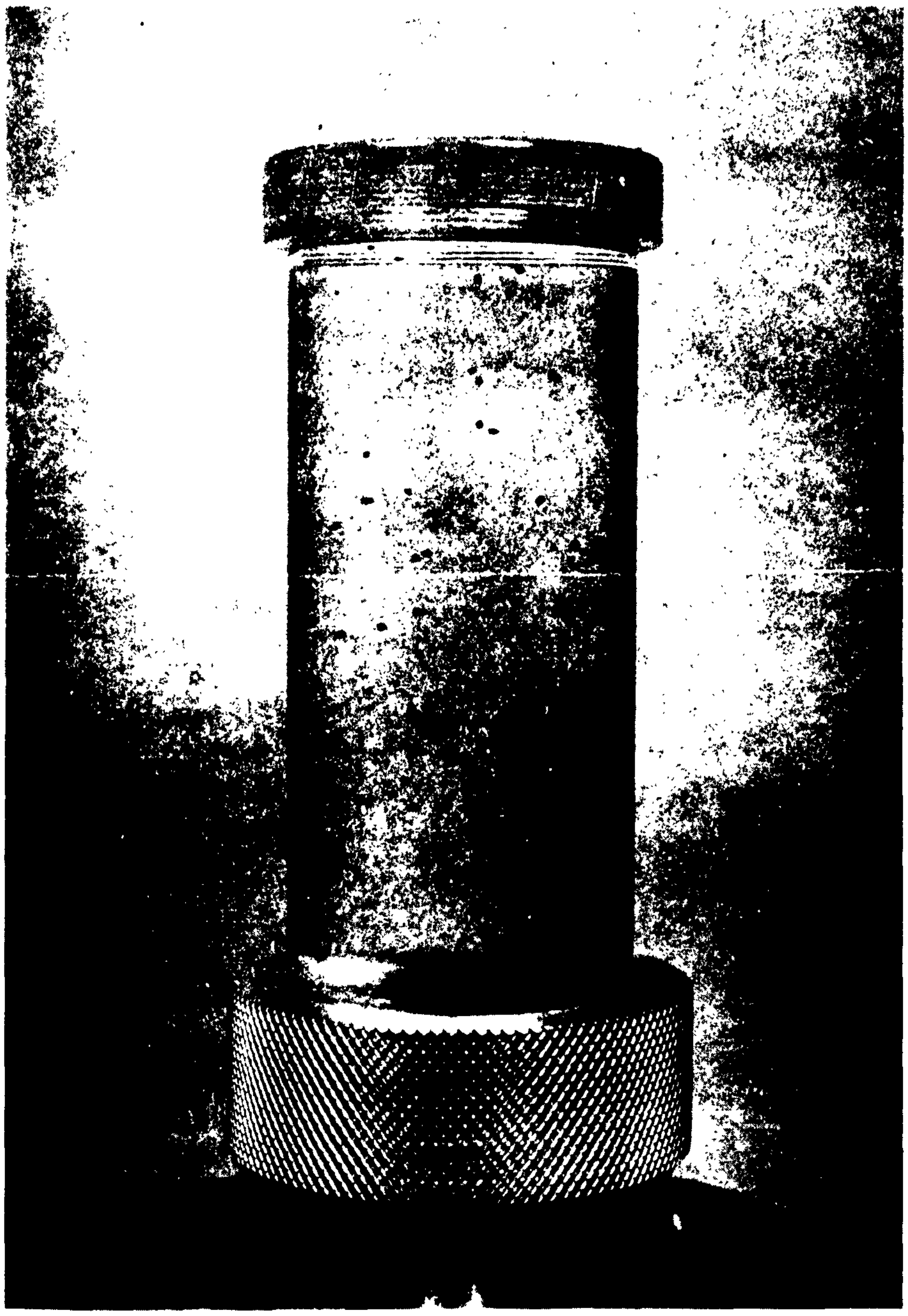


FIGURE 2

SCALE PHOTOGRAPH OF PARTICLES USED IN THE EXPERIMENTS

FIGURE 3

(98 percent glycerin-water solution; anthracene particles coated with india ink)



PARTICLES TRAJECTORIES

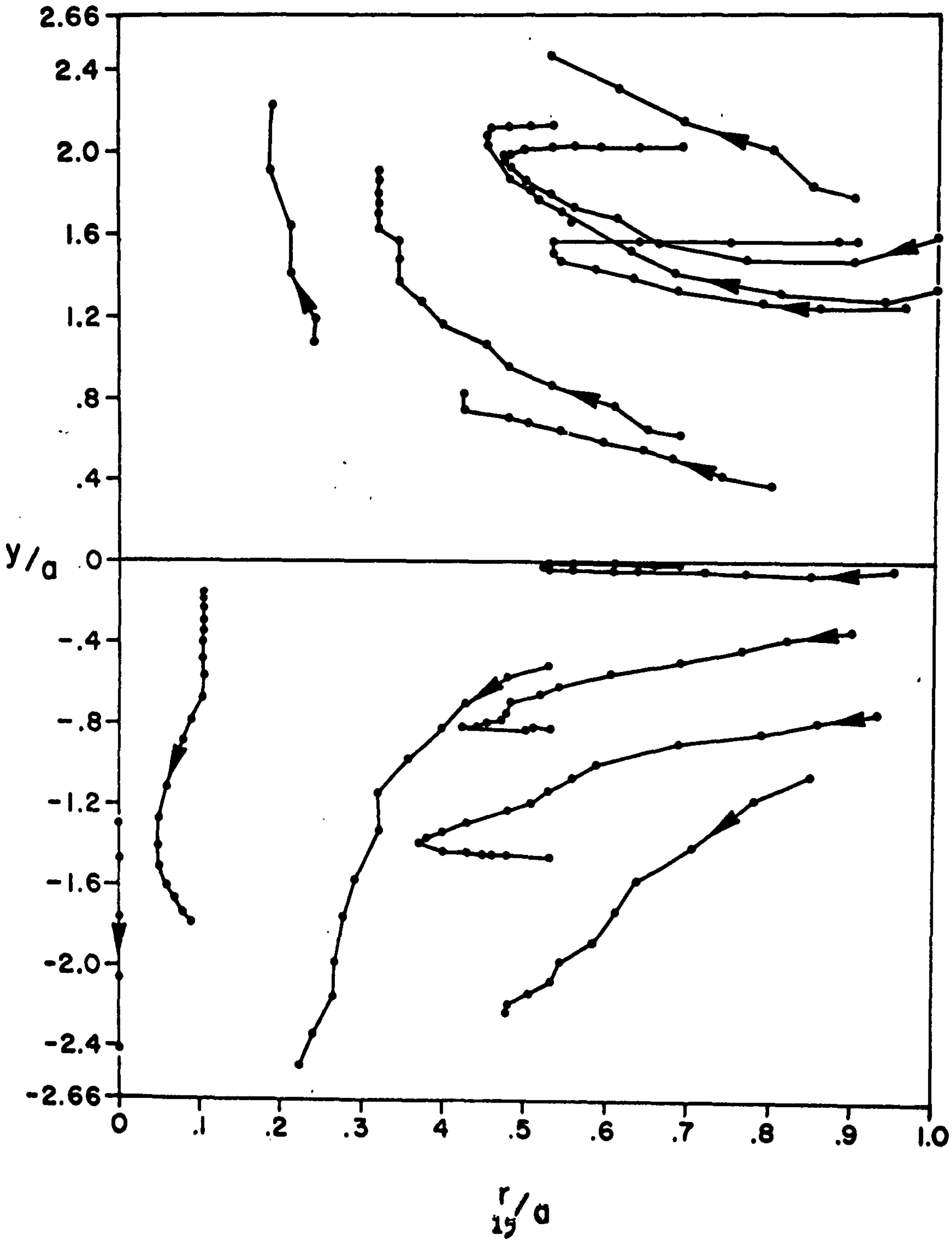
LIQUID FILLED CYLINDER STARTED IMPULSIVELY AT ω_0 = 3065 RPM

FIGURE 4

LIQUID = WATER + GLYCERIN

a = 1.88 cm ρ = 1.12 gms/cm^3 ν = .062 STOKES

POSITION OF PARTICLES AT 0.25 SECONDS INTERVALS



DISTRIBUTION OF VORTICITY WITHIN SPINNING CYLINDER

FIGURE 5. STARTED IMPULSIVELY AT ω_o

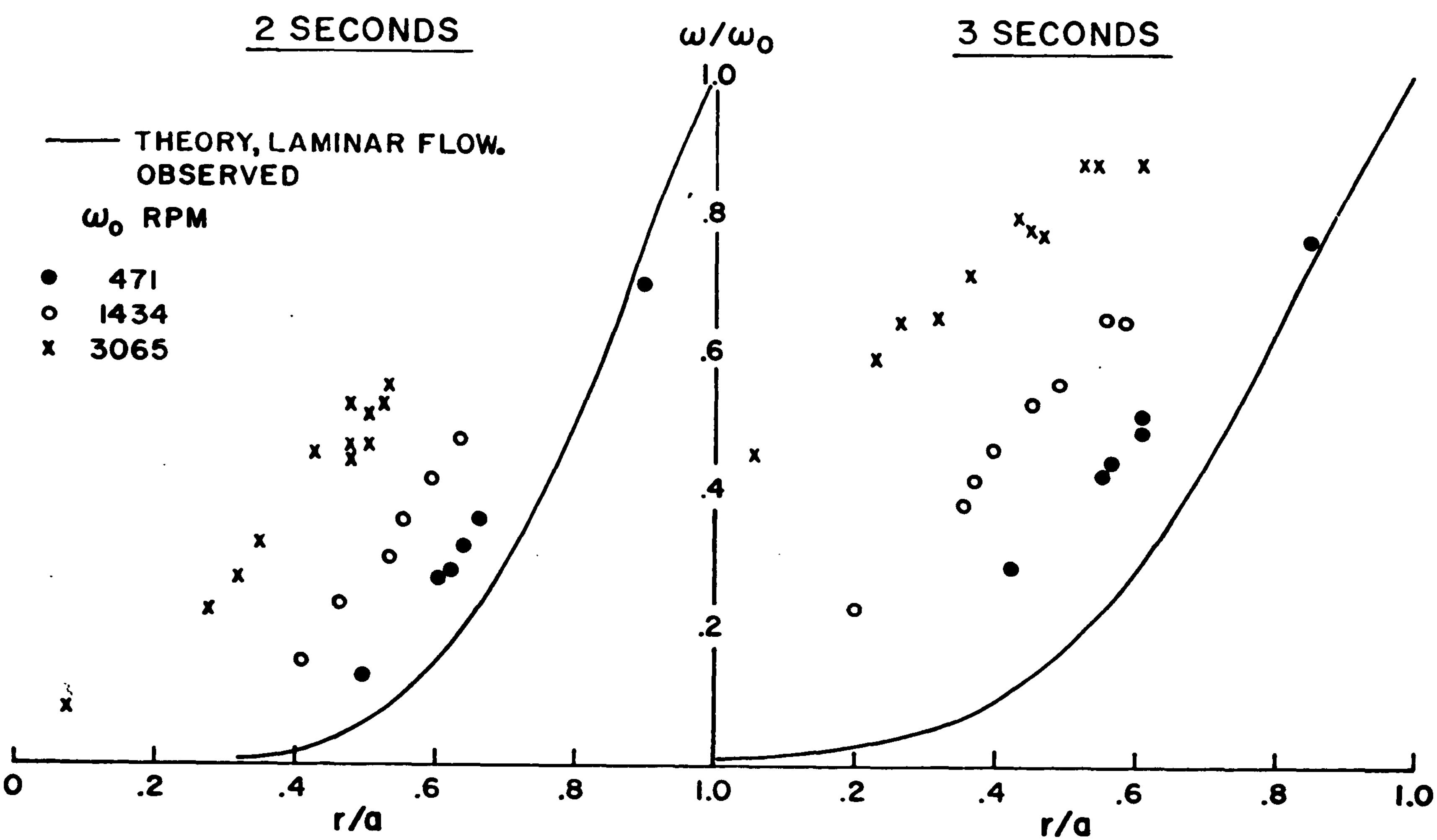


FIGURE 6. Effect of Geometry of the Cylinder on Secondary flows. The cylinders are of fineness ratios of 2.88, 5.78, and 1.44 respectively.

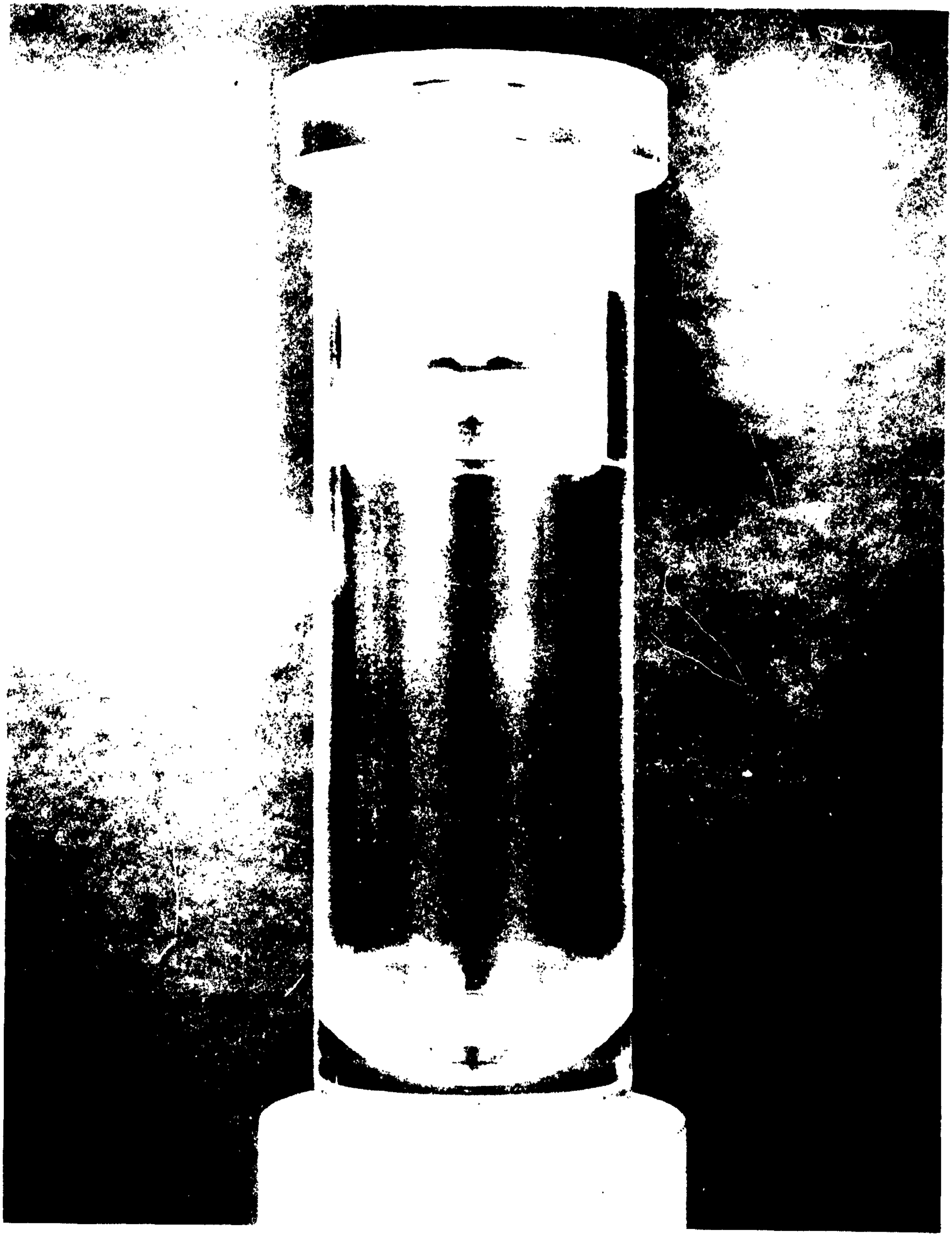


FIGURE 7. A cylinder with hemispherical ends.

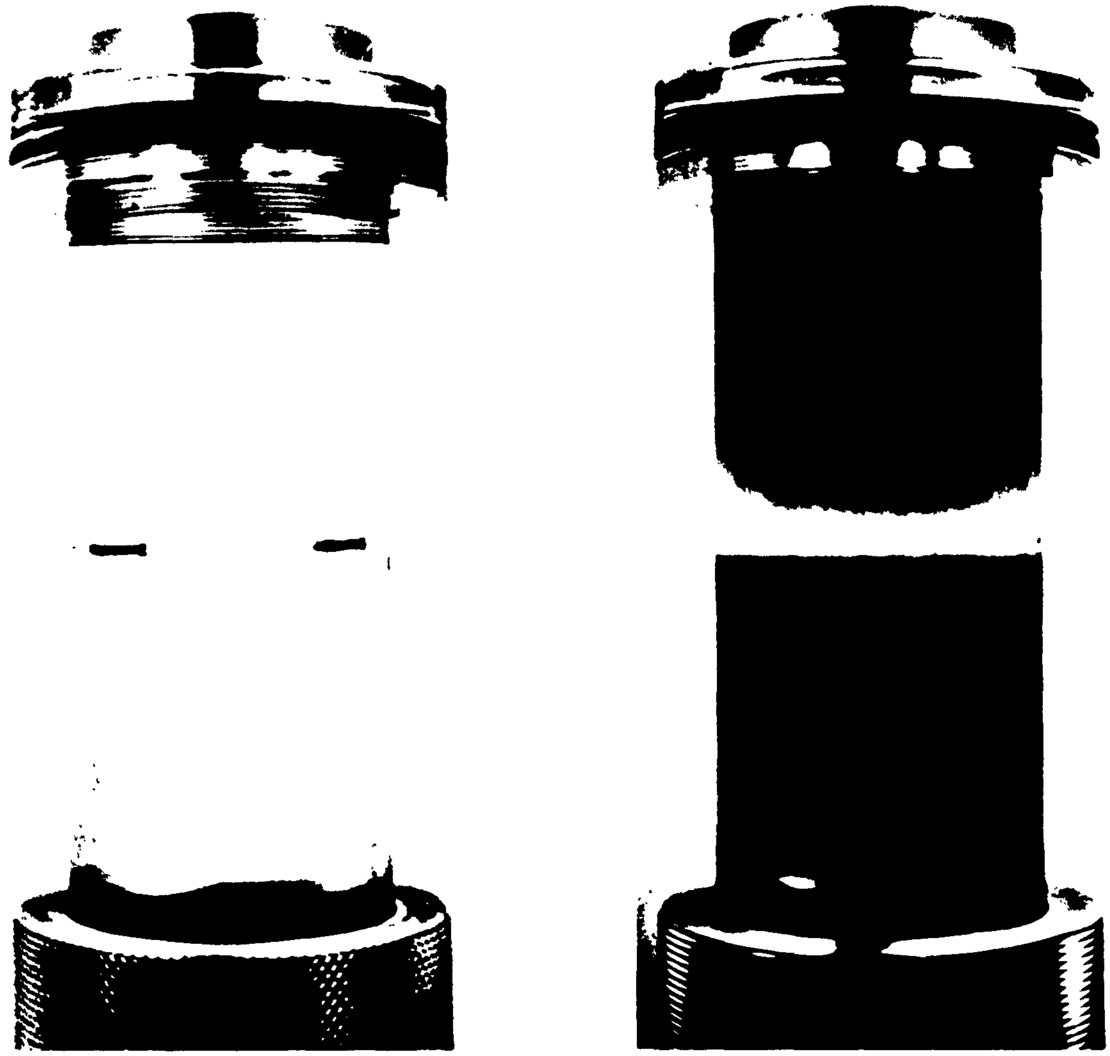


FIGURE 8. Dye experiment showing two cell structure of secondary flows in a spinning cylinder started impulsively from rest.

T = 0 T = 60 sec.

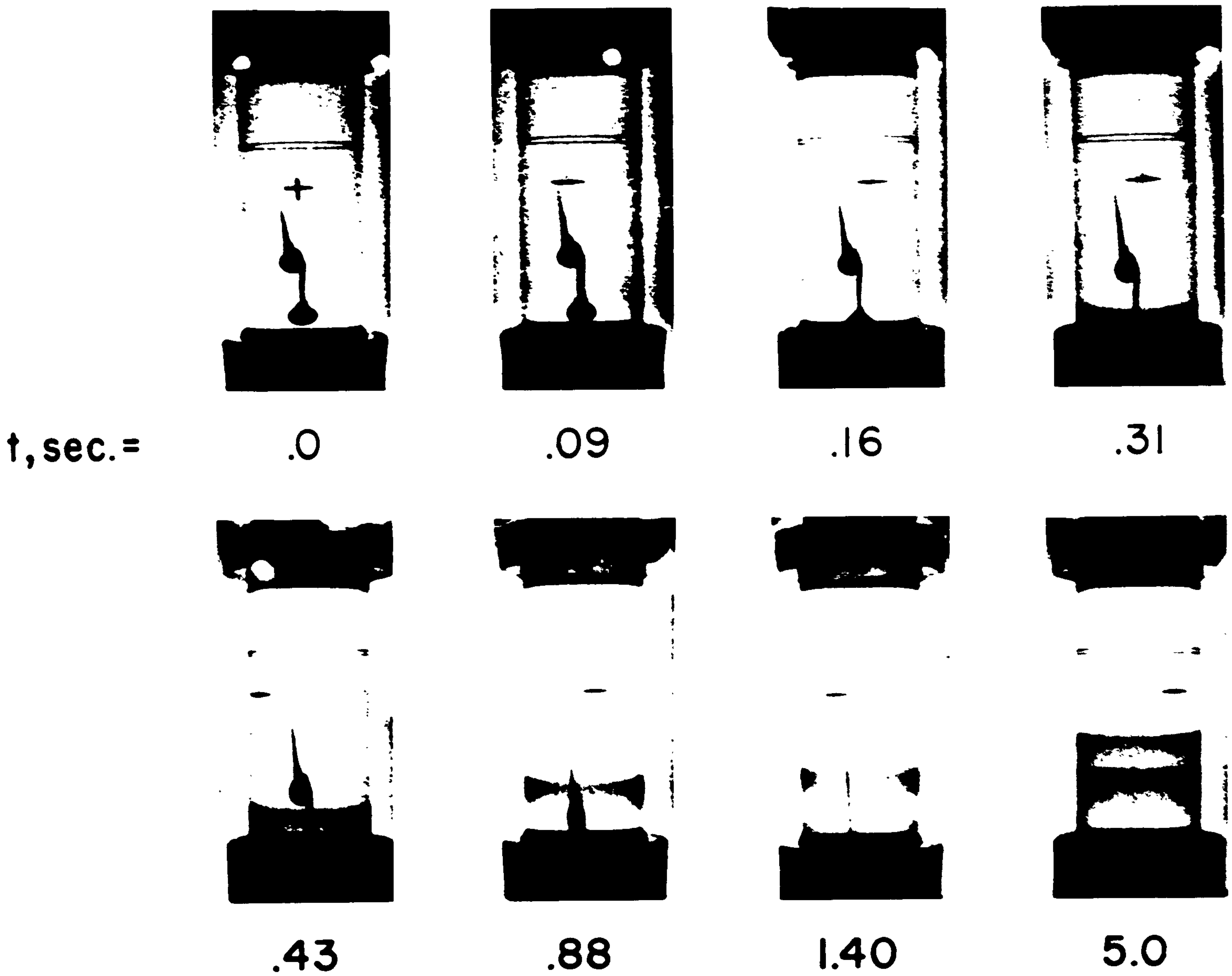


FIGURE 9. Sequence of photographs showing the development of secondary flow.

DISTRIBUTION LIST

No. of Copies	Organization
10	Commander Armed Services Technical Information Agency ATTN: TIPCR Arlington Hall Station Arlington 12, Virginia
1	Commanding General U.S. Army Materiel Command ATTN: AMCRD-RS-PE-Bal Research and Development Directorate Washington 25, D.C.
1	Commanding Officer Diamond Fuze Laboratory ATTN: Technical Information Office Branch 012 Washington 25, D.C.
2	Commanding General Frankford Arsenal ATTN: Library Branch, 0270, Bldg. 40 Philadelphia, Pennsylvania
3	Commanding Officer Picatinny Arsenal Dover, New Jersey
3	Commanding General U.S. Army Missile Command Redstone Arsenal, Alabama
1	Commanding Officer Camp Dietrick Frederick, Maryland
1	Professor of Ordnance United States Military Academy West Point, New York

No. of Copies	Organization
4	Chief, Bureau of Naval Weapons ATTN: DIS-33 Department of the Navy Washington 25, D.C.
2	Commander Naval Ordnance Laboratory White Oak Silver Spring 19, Maryland
1	Commanding Officer U.S. Naval Air Development Center Johnsville, Pennsylvania
1	Commander U.S. Naval Ordnance Test Station China Lake, California
1	Superintendent U.S. Naval Postgraduate School Monterey, California
1	Commander U.S. Naval Weapons Laboratory Dahlgren, Virginia
2	Commander U.S. Naval Missile Center Point Mugu, California
1	Commanding Officer and Director David W. Taylor Model Basin ATTN: Aerodynamics Laboratory Washington 7, D.C.
5	Scientific and Technical Information Facility ATTN: NASA Representative (S-AK/DL) P.O. Box 5700 Bethesda, Maryland

DISTRIBUTION LIST

No. of Copies	Organization
2	Armour Research Foundation Illinois Institute of Technology Technology Center Chicago 16, Illinois
2	Applied Physics Laboratory The Johns Hopkins University 8621 Georgia Avenue Silver Spring, Maryland
2	The Johns Hopkins University ATTN: Dr. O. M. Phillips Mr. H. M. Stoller Engineering Department Baltimore 18, Maryland
1	University of Minnesota ATTN: Mr. Gene Sokol Department of Mechanics and Materiels Minneapolis, Minnesota
10	The Scientific Information Officer Defense Research Staff British Embassy 3100 Massachusetts Avenue, N.W. Washington 8, D.C.
5	Defence Research Member Canadian Joint Staff 2450 Massachusetts Avenue, N.W. Washington 8, D.C.